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Effect of ionic liquid on transfer characteristic of graphene channel on PZT

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1. Introduction

Recently, the improvement of carrier motilities of graphene on the epitaxially grown ferroelectric substrate has been reported [1]. It was concluded that the charged sites on the insulator are effectively screened due to the large dielectric constant of ferroelectric material. For field effect transistors (FETs) with the ferroelectric gate insulator, the hysteresis loop observed on the transfer characteristics is expected to be the clockwise manner, while the hysteresis observed on the usual graphene device with SiO_2 gate shows the anticlockwise manner. The transfer characteristics have been reported on graphene FETs with organic ferroelectric gate insulator [2]. The use of polycrystalline ferroelectric material is crucial for the practical applications such as long life time and robust data storage. However, the expected transfer characteristics corresponding to the ferroelectric manner were hardly observed on the inorganic ferroelectric material, even on the epitaxially grown ferroelectric crystal [3]. The improvement of the transfer characteristics with top dielectric medium on gate capacitance for a SiO_2 gate graphene FET has been reported [4]. In this study, we investigate the effect of ionic liquid as a dielectric medium on the gate channel for graphene with a polycrystalline ferroelectric thin film.

2. Device fabrication

$PbZr_{0.52}Ti_{0.48}O_3$ (PZT) thin film with a thickness of 400nm was prepared by the sol-gel method on $Pt/Ti/SiO_2/Si$ substrates. The source solution of PZT was spin-coated, dried at 150°C and baked at 300°C for each coating. These processes were repeated to obtain the appropriate PZT thickness. After baking at 300°C and crystallization annealing at 670 °C for 10 min, polycrystalline PZT film was obtained. The resultant PZT film had a (101) preferred orientation by X-ray diffraction and showed a P-E hysteresis loop with a remnant polarization of 10 $\mu C/cm^2$ as shown in Fig. 1. Mechanically exfoliated graphite flakes by a Scotch tape method from Kish graphite were put on the PZT film.

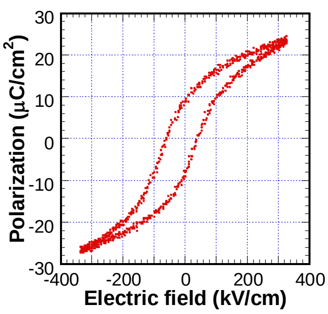

Fig.1 P-E loop

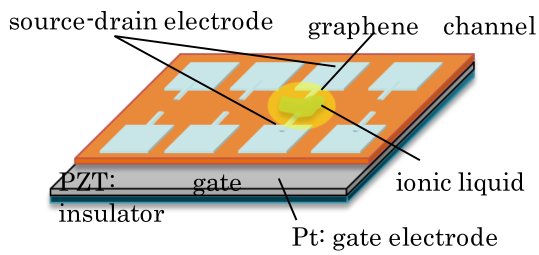

Fig.2 Schematic structure of PZT-graphene-FET

A pair of source-drain electrodes was fabricated on a few layer graphene by using electron beam lithography process. Afterwards, the ionic liquid was dropped on the graphene channel. Figure 2 shows schematic structure of PZT gate graphene-FET. Thus, the gate voltage induces the charge in the graphene channel through not only the PZT gate directly but also the ionic liquid through the PZT gate.

3. Results and discussions

Figure 3 shows transfer (I_d-V_g) characteristic for the PZT-graphene-FET before applying the ionic liquid. As-prepared PZT-graphene FET exhibits no ferroelectric gate characteristics in the transfer characteristics. The hysteresis shows anti-clockwise manner as usual FETs with SiO_2 gate insulator and shows large hysteresis. This is likely due to the charge injection to contaminants, the surface states and so on. The Dirac point corresponding to the gate voltage around -1.5 V is much smaller than that for the SiO_2 gate graphene FETs because of the high dielectric constant of the PZT. However, the transconductance shown here is much smaller than the expected transfer conductance based on the dielectric constant of PZT. This may be due to the insufficient contact between the graphene layer and the PZT and charged impurity on the PZT-graphene interface. This hypothesis is supported by

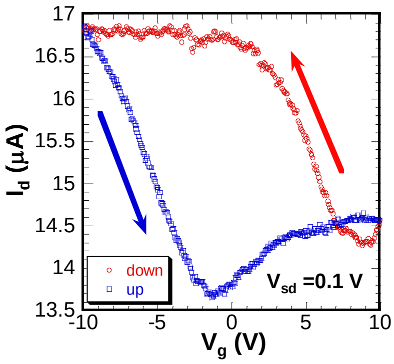

Fig.3 Transfer characteristic of PZT-graphene-FET. Arrows indicate the sweep directions of V_g.

the fact that the surface roughness of PZT is much larger than the SiO_2. Furthermore, the hysteresis became larger after the annealing around 400 °C in the vacuum. This implies that the adsorbed water thin layer on the PZT improves the capacitive coupling between the gate and the graphene channel due to the relatively high dielectric constant of water of ~80. Consequently, the insufficient gate coupling degrades the transfer characteristics shown in Fig. 3.

To improve the capacitive coupling between the gate and the graphene channel, we covered the graphene channel with the ionic liquid. Figure 4(a) shows the transfer characteristic just after the application of ionic liquid. The transconductance is improved from 0.47 to 0.77 μS. The hysteresis is almost vanished. Thus, the application of the ionic liquid is effective to improve the gate coupling and to screen the stray charge on the PZT. However, the hysteresis still showed the anticlockwise manner, so that the ferroelectric response of the PZT gate insulator was not appeared. This implies that the surface of the graphene channel is sufficiently couples to the gate voltage, although the interface between the graphene and the graphene channel still affects the transfer characteristic. This may be due to the high viscosity of the ionic liquid. Furthermore, the Dirac point for increasing the gate voltage indicated by blue line shifts toward the higher voltage. Thus, the trapped charge is still present (not compensated) on the PZT surface.

Figure 4(b) shows the transfer characteristics after a few days. Although the transconductance of the device degraded to 0.17 μS, the hysteresis loop shows clockwise manner which is expected from the polarization inversion of the PZT ferroelectric gate insulator. The degradation of the transconductance may be due to the impurity in the ionic liquid or the decrease of the effective source drain electric field due to the screening of the electric field by the ionic liquid. The development of the hysteresis loop corresponding to the ferroelectric properties of the PZT implies that some part of the graphene-PZT interface was filled with the ionic liquid.

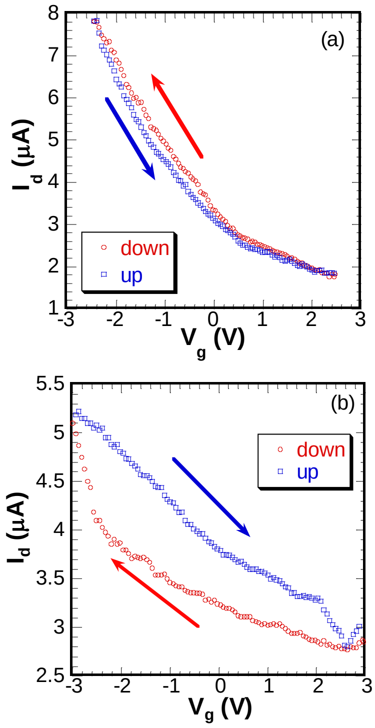

Fig.4 (a) I_d-V_g property after dropping ionic liquid, (b) I_d-V_g property after a few days.

4. Conclusions

We have investigated the transfer characteristic of the few layer graphene applying the ionic liquid on the polycrystalline PZT gate insulator. The application of the ionic liquid induces the improvement of the transconductance. The hysteresis loop observed on I_d-V_g property showed a clockwise manner which corresponds to the ferroelectric manner of the PZT. Thus, we have realized the effective coupling of the gate potential to the graphene channel by covering the graphene with the ionic liquid. We believe that this is useful for screening the charged impurity or fixed charge on the insulator for graphene transistors.

Acknowledgements

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